



CARBON AND NITROGEN MINERALIZATION OF ADDED PARTICULATE AND MACROORGANIC MATTER

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Summary—Particulate organic matter (POM) is more sensitive than total SOM to changes in management practices and, accordingly, may indicate changes in soil quality. A soil incubation study was conducted to determine the effects of added POM (75 to 250 μm size fraction), or macroorganic matter (MOM, 250 to 2000 μm size fraction) on C and N mineralization and microbial C and N content. A 1 kg composite made from 16 predominantly silt loam soils was amended with 10 g of POM, MOM or MOM ground to a reduced size of 75 to 250 μm (GMOM). The MOM amendment equaled 4.55-fold and POM equaled 1.60-fold of total MOM and POM found in the composite soil. Carbon mineralization of MOM and POM after 8 weeks was approximately 9 and 4%, respectively of the total MOM and POM-C added. Reducing the size of MOM to 75 to 250 μm did not affect mineralization. Nitrogen mineralization was slightly greater in the amended soils after 8 weeks and equaled 5 to 6% of the MOM or POM-total N added. Contribution of POM to total mineralized N from soil organic matter (SOM) in the composite soil was proportional to the POM content in SOM or approximately 12%. Amended soils had 25 to 42% more biomass-C than the control soil 2 weeks after amendment application. After 8 weeks, the amended soils contained about 32% more biomass-C. This increase in biomass-C at 8 weeks accounted for approximately 2% of the added C. At 8 weeks, microbial biomass-N in GMOM-, MOM- and POM-amended soils was about 56, 46 and 14% higher, respectively, than in the control soil. These increases were approximately 8% of the MOM-N added and 2% of the POM-N added. Increases in POM resulted in increases in soil respiration and microbial biomass-C and N, which also are suggested indicators of soil quality. Therefore, POM may be a suitable soil quality indicator that provides similar information as soil respiration or microbial biomass determinations. © 1998 Published by Elsevier Science Ltd. All rights reserved

INTRODUCTION

Soil organic matter (SOM) is widely recognized as a critical component of soil quality and productivity (Arshad and Coen, 1992; Granatstein and Bezdicsek, 1992) because of its influence on nutrient cycling processes, soil structure, water availability and other important chemical, physical and biological properties of soil. Soil quality refers to the capacity of a soil to function within ecosystem boundaries, to sustain biological productivity, maintain environmental quality and promote plant and animal health (Doran and Parkin, 1994); it is as essential to environmental quality as air and water quality (National Research Council, 1993). Soil organic matter consists of all the organic constituents in soil (exclusive of living plants and animals), including partially-decomposed plant and animal residues and well-decomposed organic residues that vary considerably in their stability and susceptibility to further decomposition.

Density of soil organic matter particles is used to separate light and heavy fractions. Densities of light fractions range from 1.6 to 2.0 Mg m^{-3} . Light fraction is further divided by size where $>250 \mu\text{m}$ is characterized separately as macroorganic matter (MOM) (Barley, 1955; Theng *et al.*, 1989). The particulate organic matter (POM) fraction, i.e. the 53 to 2000 μm fraction obtained by a chemical dispersion–physical size separation technique (Cambardella and Elliott, 1992), is similar to the light fraction (LF) originally described by Greenland and Ford (1964) and to the floatable organic matter fraction described by Tiessen and Stewart (1983). Biologically, they react similarly. Elliott *et al.* (1994) showed that POM-C is more sensitive to changes in soil management and cropping practices than are total SOM or microbial biomass-C. The light fraction is also more sensitive to changes in cropping practices than is total SOM (Shaymukhametov *et al.*, 1984; Dalal and Mayer, 1987; Skjemstad *et al.*, 1988) or mineralized and microbial C and N (Biederbeck *et al.*, 1994). The LF is also highly labile (Dalal and Mayer, 1986, 1987; Janzen, 1987; Janzen *et al.*, 1992). Although

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Cambardella and Elliott (1992) described POM as a pool of stabilized organic matter, they showed that as much as 40% of the POM could turnover in a cropping season.

Soil N mineralization is an important factor in the determination of soil quality (Duxbury and Nkambule, 1994), but surprisingly, N mineralization of the LF has been measured only rarely (Boone, 1994). Considerable differences of opinion exist on the contribution of LF to net soil N mineralization. Ford and Greenland (1968) reported that LF accounted for 25 to 60% of net mineralized N. Janzen (1987) reported that the LF-N content of soils was significantly correlated with net N mineralization of soil. Sollins *et al.* (1984), Theodorou (1990) and Boone (1994) showed, however, that the heavy fraction (HF) is the principal N source for plants in soil.

Because of the recent emphasis on POM and LF as possible indicators of changes in SOM and therefore soil quality (Sikora *et al.*, 1996), studies were conducted to determine the C and N mineralization of POM and MOM fractions in soil. Results were evaluated to determine the possible role these fractions play in soil quality and crop productivity.

MATERIALS AND METHODS

The decomposability of SOM is often studied by using a "whole soil approach" in which the CO₂ production and N mineralization of unfractionated soil samples are assessed. However, additional information may be gained by the incubation of isolated fractions (Christensen, 1987). It may be argued that drawing conclusions from incubations of an isolated fraction and applying them to whole soil transformations is not entirely valid since the physical and chemical conditions of the fractions obtained from soil are not identical to whole soil (Bernhard-Beverat, 1981; Christensen, 1987). We incubated both soil alone and soil with added POM or MOM and assumed that there is no difference between the mineralization rate of "native" and added POM or MOM and all differences in mineralized C and N in the amended soils are the result of added POM and MOM.

Soil samples were collected in the spring from a 16 ha Cropping Systems Research Project site at the Beltsville Agricultural Research Center where the site had been in alfalfa hay for 8 y followed by 1 y of no-till corn. The long-term history of the site was pasture of uniformly-managed field crops for 60 y (Lengnick, 1997). Sixteen soil samples (0 to 20 cm) were taken every 15 m along a 225 m transect which covered six of the eight soils types and the highest and lowest elevations at the site. Maximum slope was 3%. The soils at the site were identified as mainly Typic Hapludults (Downer sandy loam, Keyport silt loam, Matapeake silt

loam, Mattapex silt loam) with two Typic Ochraquults (Elkton silt loam, Othello silt loam) and a Typic Paleudults (Christiana silt loam) soils. The soil samples were air-dried and sieved (2 mm). Macroorganic matter was extracted from each individual soil sample by first washing the samples on the 250 μ m screen using deionized water. The material that remained on the screen was then separated by flotation on water into MOM and sand fractions. Fractions were dried at 70°C and weighed. A pooled sample of MOM fractions collected from 16 soil samples of equal mass was ground in a mortar and pestle and sieved to obtain a 75 to 250 μ m fraction (GMOM). The purpose of grinding was to find the effect of particle size on mineralization of the MOM fraction (Jensen, 1994). The POM was isolated using the procedure described by Cambardella and Elliott (1992) with two modifications: (1) soil was dispersed in 5 g hexametaphosphate I⁻¹ and passed through a 75 μ m sieve instead of a 53 μ m sieve; (2) the MOM fraction was removed before isolation of the POM fraction. The POM was washed 6 to 8 times on the sieve with deionized water to remove residual hexametaphosphate. To obtain a sufficiently large, uniform POM sample for mineralization studies, a composite sample of all 16 soils sieved to remove MOM (250 μ m) was used to isolate POM.

POM, MOM and GMOM were added in 10 g amounts to 1 kg of composite soil screened to remove MOM. This procedure provided the opportunity to determine the effect of removal and re-addition of MOM that cannot be accomplished with POM. The composite soil contained 16.5 g POM kg⁻¹ and the additional POM resulted in a treatment equaling 1.6 times the amount present in the composite; the MOM content of the composite soil before screening was 2.2 g kg⁻¹ and with the addition of 10 g MOM or GMOM, the treatments contained 4.55 times the amount originally present. After thorough mixing, 5 g samples were placed in glass vials for N mineralization and biomass-C and N determinations and 20 g were placed into four replicate biometer flasks for C mineralization studies at 25°C. Moisture was adjusted and maintained at 297 g H₂O kg⁻¹ soil (60% water-holding-capacity). Composite sieved soil (2 mm) was chosen as a control to obtain mineralization rates of relatively intact soil. Using soil sieved to 250 μ m as the control would result in greater mineralization than intact soil because sieving causes aggregate disruption. Differences between treatments are not affected because all treated soils were sieved to 250 μ m.

Organic C in soils, MOM and POM were determined by dichromate digestion (Dyakonova, 1977) and organic N was determined by the Kjeldahl method (Bremner and Breitenbeck, 1983). Lignin content of MOM and POM was determined by the

Table 1. Properties of MOM and POM (mean values \pm 95% confidence interval) added to composite soil

Characteristic	MOM	POM
Size (μm)	250–2000	75–250
C (%)	22.8 \pm 0.8	14.7 \pm 0.7
N (%)	1.39 \pm 0.07	1.17 \pm 0.13
C to N ratio	16.4 \pm 1.0	12.6 \pm 1.5
Ash (%) [†]	58.4 \pm 1.1	71.7 \pm 0.8
Lignin (% on ash free base)	43.3 \pm 2.3	53.4 \pm 14.5
Lignin to N ratio	12.9 \pm 1.0	12.9 \pm 3.8

[†]Ash and lignin analyses were performed on POM and MOM obtained from the composite soil sample. Therefore, the confidence interval describes variation in the analysis. Carbon and N analyses were performed on POM and MOM obtained from 16 individual samples; the confidence interval describes the variation across the 16 soil samples.

method of Goering and Van Soest (1970). Inorganic N, biomass-C and N were determined on three replicate vials sampled at 1, 2, 3, 4, 6 and 8 weeks. Week 1 biomass-N samples were inadvertently destroyed. Carbon dioxide was collected in NaOH and measured by back-titration with HCl to the phenolphthalein end point after precipitation of carbonates with saturated BaCl₂ (Anderson, 1982).

Carbon and N contents of the microbial biomass were determined by chloroform fumigation–extraction technique (Brookes *et al.*, 1985; Vance *et al.*, 1987). Soils were extracted before and after fumigation with 0.5 M K₂SO₄ for 60 min (soil:extract ratio = 1:4). Organic C in the soil extract was measured by dichromate digestion (Aseeva *et al.*, 1991). Biomass-C was then estimated using the equation $B_c = 2.64E_c$ (Vance *et al.*, 1987) where E_c = [organic C extracted from fumigated soil – organic C extracted from unfumigated soil]. Biomass-

N was calculated from $B_n = 2.22E_n$ where E_n = [total N extracted from fumigated soil – total N extracted from unfumigated soil] (Brookes *et al.*, 1985; Jenkinson, 1988). Total ammonium-N was measured by the acid-peroxide digestion procedure (Hossain *et al.*, 1993) after nitrate in extracts was reduced using Devardo's alloy. Net mineralization was calculated by subtracting the quantity of inorganic N present at time zero from that present at each sampling time.

RESULTS

Analysis of MOM or POM from 16 individual soil samples or from the composite soil sample showed that MOM had a higher percent C content and a C to N ratio but a lower percent ash and lignin than POM (Table 1). MOM-C ranged from 0.27 to 0.98 g kg⁻¹ soil and POM-C ranged from 1.5 to 3.4 g kg⁻¹ soil or approximately four times that of the MOM-C concentration (data not presented).

Addition of POM or MOM to soil increased the C mineralization (Fig. 1). Carbon dioxide evolution from MOM-amended soils was significantly higher after 8 weeks than from POM-amended soils (*t*-test, $P = 0.05$). Carbon mineralization of GMOM-amended soil was not different from unground MOM-amended soil. Carbon mineralization from POM-amended soil was significantly greater after 8 weeks than the control soil. After subtracting C mineralized from the control, 9% of MOM-C and 4% POM-C mineralized in 8 weeks. Any “priming effect” was considered negligible based on con-

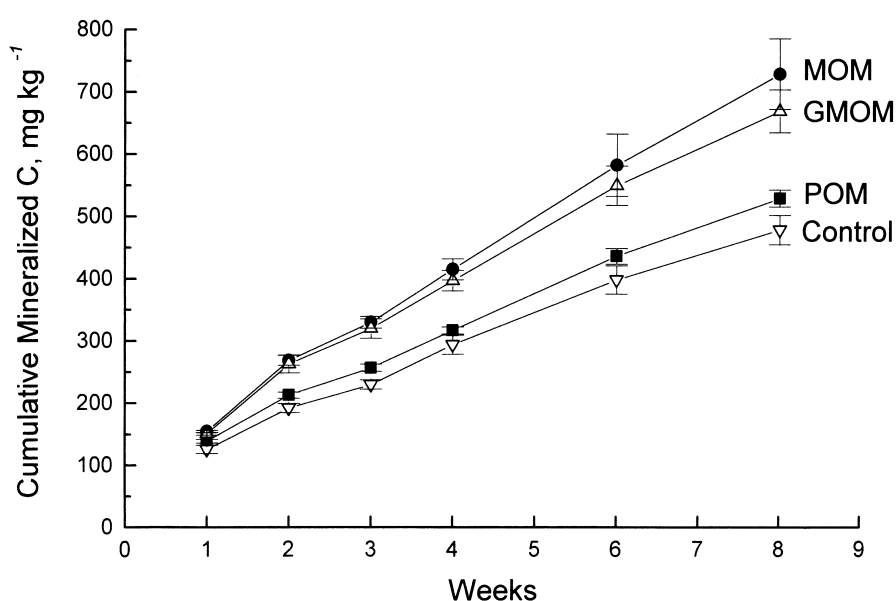


Fig. 1. Cumulative C mineralized (mean and SE mg C kg⁻¹ soil) in soil amended with POM or MOM fractions

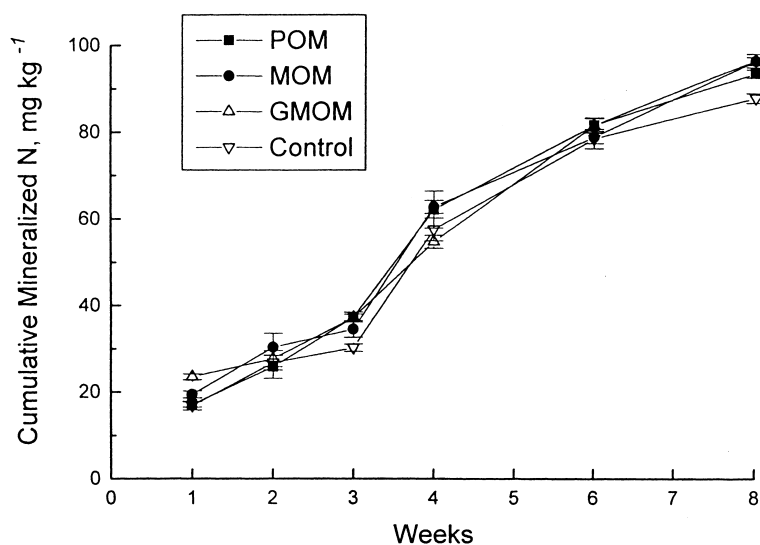


Fig. 2. Cumulative N mineralization (mean and SE mg N kg⁻¹ soil) in soil amended with POM or MOM fractions

clusions from similar soil incubation studies using compost amendments (Sikora and Yakovchenko, 1996).

Cumulative N-mineralization of POM, MOM, GMOM and soil alone was not different at 2, 4 and 6 weeks (Fig. 2). At 8 weeks, the amended soils had slightly higher cumulative N-mineralization than the control soil. GMOM had a slightly higher mineral N content than the other treatments at week 1. Net cumulative N mineralization (subtracting N mineralization of the control) after 8 weeks was approximately 6 mg or 5.1% of the POM-N and 9 mg or 6.6% MOM-N added. Carbon and N mineralization rates were similar for POM (4 to 6%), but MOM-N mineralization was approximately half the

MOM-C mineralization (5 vs 9%). These results may be related to the C to N ratios of MOM and POM which were 16.4 and 12.6, respectively.

Nitrogen mineralization of SOM minus POM was calculated by subtracting the mineral N attributed to POM (approximately 10 mg N kg⁻¹) from total N mineralized (88 mg N kg⁻¹) and dividing by organic N minus the POM N content (1670 – 193 mg N kg⁻¹). This rate equaled 5.5% at 8 weeks. Because the N mineralization rates of POM and other SOM fractions were approximately the same, the contribution of POM to total mineralized N in the composite soil was, thus, proportional to the POM content in SOM or approximately 12% (193 of 1670 mg N kg⁻¹).

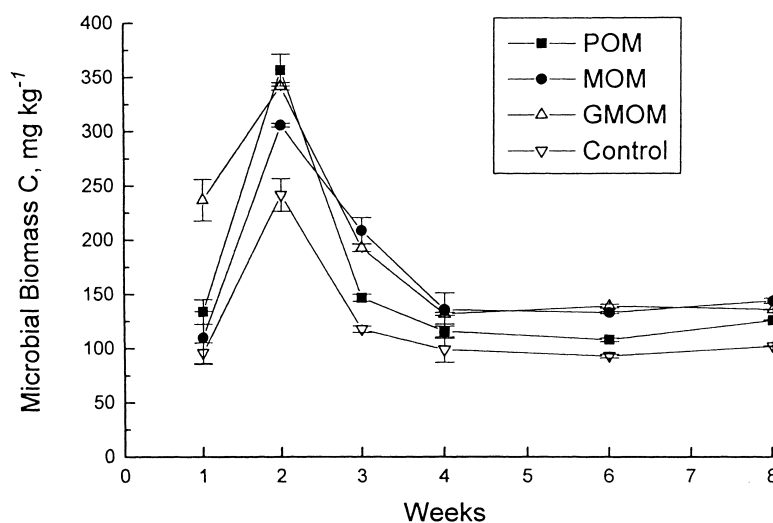


Fig. 3. Changes in microbial biomass-C content (mean and SE mg C kg⁻¹ soil) with time in soils amended with POM or MOM fractions

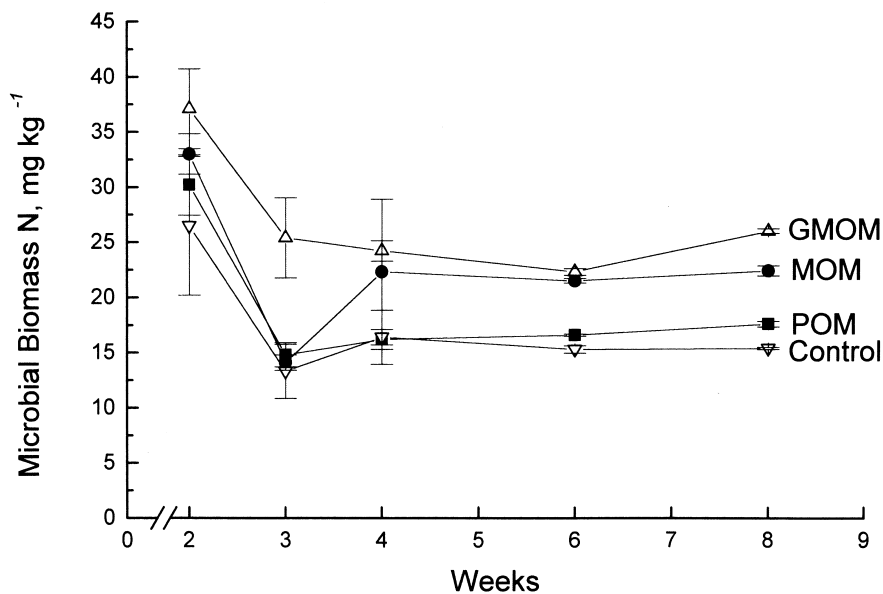


Fig. 4. Changes in microbial biomass-N content (mean and SE mg N kg⁻¹ soil) with time in soils amended with POM or MOM fractions

Microbial biomass-C contents in all treatments peaked at 2 weeks, then decreased to amounts at or below those at 1 week (Fig. 3). Amended soils had 25 to 42% more biomass-C than the control soil at 2 weeks but at 8 weeks the amended soils contained about 32% more biomass-C. This increase in biomass-C at 8 weeks over control soil accounted for approximately 2% of the added POM- or MOM-C. A similar pattern of decrease from 2 week values was seen for microbial biomass-N (Fig. 4). At 8 weeks, microbial biomass-N in GMOM-, MOM- and POM-amended soils was about 56, 46 and 14%, respectively, higher than the control soil. These increases equal approximately 8% of the MOM-N added and 2% of the POM-N added. In summary, at 8 weeks microbial biomass-C and N contents were significantly greater in the amended soils than unamended soil ($P = 0.05$). Overall, MOM-amended soils, especially GMOM, had greater biomass-N contents than POM-amended and unamended soils.

DISCUSSION

The POM fraction consists of partially-decomposed pieces of plant residue and has a density of $< 1.85 \text{ g cm}^{-3}$, whereas the LF of SOM (Greenland and Ford, 1964), has a similar density ($< 2.0 \text{ g cm}^{-3}$) and a C to N ratio of near 20. For the purposes of this discussion, we consider LF SOM to be equivalent to POM as prepared by Cambardella and Elliott (1992) and the POM prepared in this study. The MOM is also considered equal to LF (Theng *et al.*, 1989), but in the 16 soils extracted,

the MOM-C content was only 25% of the amount of POM-C present in the soils.

The more advanced state of decomposition of POM compared to MOM is reflected by higher ash content, more narrow C to N ratio, and lower C mineralization rate (Table 1). Carbon to nitrogen ratios of LF isolated by the method used by Greenland and Ford (1964) or by other methods ranged from 11.5 to 28.9 (Sollins *et al.*, 1984; Dalal and Mayer, 1987). Cambardella and Elliott (1992) reported C to N ratios of 11.7 to 20.1 for POM. The ash content of LF usually exceeds 50% (Greenland and Ford, 1964; Ford *et al.*, 1969) and the C content is considerably below 25% (Turchenek and Oades, 1979), a value that is similar to that found for POM in our study.

Increasing the amount of POM in the composite soil by 60% led to a small but significant increase of C mineralization. Bremer *et al.* (1994) reported that the relationship of mineralized C to LF-C was highly significant ($P < 0.001$), but only accounted for 31% of the variation in mineralized C.

The MOM-amended soils mineralized nearly 50% more C than the unamended soil, but the amount of C added as MOM was also large, approximately 5 times that of the composite soil. Interestingly, reducing the particle size of MOM by grinding to 75 to 250 μm size did not affect C mineralization. These data suggest that surface area of MOM does not limit mineralization.

Nitrogen mineralization was proportional to POM N content of the composite. Sollins *et al.* (1984) found net N mineralization in LF to be low and attributed it to a high C to N ratio. Bremer *et*

al. (1994) suggested that the high C to N ratio of LF suggests N immobilization was probably enhanced. The C to N ratios of the MOM and POM fractions we isolated in this study were near the lowest reported for LF or POM reducing the possibility of significant N immobilization in the amended soil. Janzen (1987) reported a highly significant correlation between the amount of N mineralized from soil and LF-N content ($R = 0.88$) for a dark brown chernozemic alluvial lacustrine loam soil at Lethbridge, Alberta. Later, in their research on long-term crop rotation studies at three sites in Saskatchewan, Canada, Janzen *et al.* (1992) reported that the correlation between LF and N mineralization was less than between LF and respiration. According to Ladd and Russell (1983), the N mineralization from LF, expressed as a proportion of organic N, may not be any different from % mineralization of SOM. Bernhard-Berversat (1981) found that during 20 d of aerobic incubation N mineralization ranged from 3 to 10% in the light fraction and 9 to 14% in the silt + clay fraction. Boone (1994) using the anaerobic incubation technique showed that LF-N is less available than N from other SOM fractions (mostly HF). Monaghan and Barraclough (1993) reported on a similar experiment in which MOM extracted from two old grass fields was added to a composite soil and N mineralization was followed in the laboratory using ^{15}N . The MOM from an organic loam mineralized significantly more than MOM from a sandy loam. Correcting for MOM originally present in the soil, they estimated that about 12 and 4.5% of the gross N mineralization could be attributed to the added organic loam and sandy loam MOM, respectively. They concluded that the MOM fraction did not contribute a substantial amount of mineral N for plant growth. Our data indicated that only 5 to 6% of the POM and MOM N was mineralized in 8 weeks. The finding that POM is generally a small portion of total SOM and mineralize at low rates suggests that it contributes little to net N mineralization in soil and the N needs of many crops.

The time of year samples are taken may affect content and POM mineralization rate. The samples evaluated in our study were taken in the spring. Boone (1994) collected soil samples monthly from April to October in a corn (*Zea mays* L.) field and found that LF content varied by a factor of 1.7. The lowest LF contents were in June and the highest in October. Boone concluded that the changes in POM content reflect the seasonality of inputs. Because LF is only a small portion of SOM, the benefit of POM increases or decreases to plant N during a growing season would be small.

The greatest difference between microbial biomass-C contents in amended soil and control soil was after 2 weeks of incubation when increases in biomass-C equaled 5 to 7% of the C added. At

8 weeks, the difference equaled only 2% of the C added. Similar increases in microbial biomass-C have been reported following crop residue and manure additions (Ocio *et al.*, 1991; Aoyama and Nozawa, 1993). Generally, addition of MOM, POM, or plant residues results in a biomass increase within 2 weeks that equals less than 12% of the C added.

Particulate organic matter may function as an N storage pool recycled by biomass with little net N mineralization. Our data showed an increase in biomass-N in the MOM-amended soils equal to about 8% of the N added. Ladd *et al.* (1981) showed that formation of microbial biomass ^{15}N reached a maximum value of 15% of the added ^{15}N -labelled residues.

Sizeable changes in POM (or LF) which occur in response to treatment suggest that these fractions may predict changes in SOM status before those changes are evident. Thus, POM appears to be a suitable indicator of soil quality. However, crop productivity changes should not be directly attributed to changes in POM. Soil organic matter does not supply adequate mineral N for optimum crop production because it generally is less than 5% of the soil's mass and mineralizes slowly. POM is a small fraction of total SOM (12–15%) and mineralizes slowly at 5 to 6% in an 8 week laboratory incubation. Therefore, the contribution of mineral or plant available N in soils that could be attributed to changes in POM is small.

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